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Differential stimulation and suppression of phytoplankton growth by ammonium enrichment in eutrophic hardwater lakes over 16 years

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RADIOLOGICAL RISKS ASSOCIATED WITH BUILDING MATERIALS AND INDUSTRIAL BY-PRODUCTS

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Abstract

To get a better insight into the radiological features of natural raw materials and industrial by-products that can be used in building materials, a review of the reported scientific data can be very useful. The current study is based on the continuously growing database of the By-BM (H2020-MSCA-IF-2015) project (By-products for Building Materials). Currently, the By-BM database contains individual data on 1095 raw materials and 431 industrial by-products used for building. It was found that radionuclide concentrations in the raw materials varied widely — from less than detection levels up to 27 851 Bq/kg for Ra-226, 906 Bq/kg for Th-232 and 17 922 Bq/kg for K-40 — while the radionuclide content of the by-products varied less widely — from 7 to 3152 Bq/kg for Ra-226 and from less than the detection limit up to 1350 and 3001 Bq/kg for Th-232 and K-40, respectively. The average Ra-226, Th-232 and K-40 concentrations in the industrial by-products were, respectively, 2.52, 2.35 and 0.39 times those in the building materials. Gamma exposure arising from bulk building products was calculated (i) using the ‘I-index’ approach described in the European Commission publication Radiation Protection 112, based on a single, fixed value for the material density and (ii) as described in IAEA Safety Standards Series No. SSG-32 using measured values of material density. It was found that in most cases the I-index approach (without consideration of the material density) resulted in a significant overestimation of effective dose.

Introduction

Radiation exposures due to minerals containing radionuclides of natural, terrestrial origin (238 U decay series, Th-232 decay series and K-40) are generally not significantly higher than normal background levels. Average worldwide activity concentrations are currently 33, 32, 45 and 412 Bq/kg for U-238, Ra-226, Th-232 and K-40, respectively [1]. In the case of building materials, average worldwide values are 50 Bq/kg for Ra-226, 50 Bq/kg for Th-232 and 500 Bq/kg for K-40 [2]. Although, these average activity concentrations are relatively low, large variations can be found and, as a result of the occurrence of anomalies, elevated concentrations can be found in some natural materials. In many cases, these materials with elevated concentrations have been used as building material. The determination of the radionuclide content of building materials and assessment of indoor exposure is therefore important because most individuals spend 80% or more of their time indoors. Chronic exposure involving moderate doses of radiation can increase the risk of health damage to individuals, which may occur decades after the exposure [3].

Building materials can be produced directly from natural materials such as rocks, granite and clay or from industrial by-products such as fly-ash, bottom ash, steel slag and bauxite tailings (‘red mud’). It is important to investigate the use of such materials in order to allow them to be safely and efficiently integrated into new and refurbished buildings. To get an insight into the radiological features of potentially

usable industrial by-products, a review of the reported scientific data is necessary. This study is based on the continuously growing database of the By-BM (H2020-MSCA-IF-2015) project. The aim of this project is to characterize the mechanical and radiological parameters of constituents and prepared By-BM geopolymers made from industrial by-products. This project is connected to, and provides information for, the NORM database COST TU 1301 NORM4Building Action.

Materials and methods

In order to draw conclusions from the scientific data embedded into the By-BM database, unified selection criteria were laid down:

- (a) To establish an overview of the scientific data, individually reported sample data for Ra-226, Th-232 and K-40 obtained by gamma spectrometry were used — the ranges of activity concentrations were not usually imported into the database. After extracting the data, criteria were applied to ensure a meaningful statistical analysis.
- (b) Average concentration values for certain materials were used only if the investigated material originated from the same site, e.g. a quarry, mine or reservoir. In the case of commercial building material, the brand and type of each sample had to be clearly mentioned in the reference to fulfil selection criteria. Furthermore, the range of the data was also checked, and the mean was used only if the minimum and maximum values were within 20% of the mean.
- (c) U-238 activity concentrations were imported into the database only if the results were obtained from the measurement of the concentrations of Rn-222 progeny (Bi-214 and Pb-214) to avoid errors due to decay chain disequilibrium.

The so-called ‘I-index’ is widely used for evaluating building materials with respect to gamma exposure [4]. The index is calculated using equation (1).

$$I = \frac{C_{Ra-226}}{300Bq/kg} + \frac{C_{Th-232}}{200Bq/kg} + \frac{C_{K-40}}{3000Bq/kg} \quad (1)$$

where C_{Ra-226} , C_{Th-232} and C_{K-40} are, respectively, the Ra-226, Th-232 and K-40 activity concentrations in becquerels per kilogram. This calculation method is based on a model described in Ref. [5] for a building constructed from concrete with a density of 2350 kg/m³ and a wall thickness of 20 cm. An I-index of 1 is specified in Ref. [6] as a conservative screening criterion for identifying materials that, when incorporated into a building in bulk quantities, might give rise to an individual dose of more than 1 mSv above background. In terms of Ref. [6], the dilution and mixing of construction materials is permitted as long as the index of the final building product itself is below a value of 1, which makes possible the mixing of by-products with low activity level raw materials.

In order to determine the dose more precisely, the actual density and thickness of the material (rather than the fixed values specified above), as well as factors relating to the type of building and the intended use of the material (bulk or superficial) need to be taken into account. In Ref. [7], the dose modelling used in Ref. [4] is again applied, but this time using the actual density and thickness of the building material.

Results and discussion

The current version of the By-BM database contains data on 1095 natural materials used for building and 431 industrial by-products, gathered from 48 countries. The worldwide distribution of data sources and information on material density and type are shown in Fig. 1 and Tables 1 and 2.

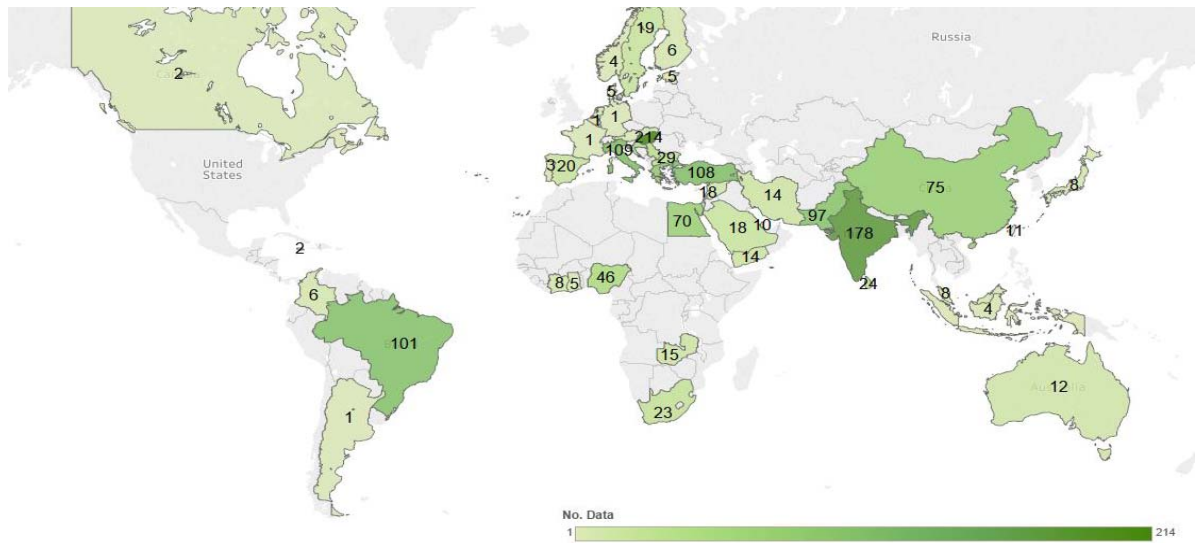


FIG. 1. Worldwide distribution of data sources for building materials.

TABLE 1. RAW MATERIALS USED FOR BUILDING

Material name	Number of data sources	Density (kg/m ³)
Aggregate	9	1900
Basalt	3	3000
Brick	243	1900
Cement	87	1500
Ceramics	94	2400
Concrete	63	2350
Cellular lightweight concrete	37	700
Granite	297	2600
Gypsum	66	865
Limestone	16	2600
Marble	72	2550
Pumice	3	650
Rock	31	2300
Sand	19	1500
Sandstone	14	2323
Serizzo	5	2650
Sienite	5	2700
Asbestos tile	4	1750
Travertine	9	2300
Tuff	10	2100
Volcanic	7	1800

TABLE 2. INDUSTRIAL BY-PRODUCTS

Material name	Number of data sources	Density (kg/m ³)
Bottom ash	59	700
Fly ash	145	720
Manganese clay	44	2800
Phosphogypsum	45	1500
Bauxite tailings (Red mud)	92	1600
Steel slag	41	2600
Residue of TiO ₂	5	4300

Individual data on Ra-226, Th-232 and K-40 activity concentrations are available for 30 different materials (23 raw materials used for building and 7 industrial by-products). In the case of the raw materials used for building, it was found that radionuclide concentrations varied widely — from less than detection levels up to 27 851 Bq/kg for Ra-226, 906 Bq/kg for Th-232 and 17 922 Bq/kg for K-40 — while the radionuclide content of the industrial by-products varied less widely — from 7 to 3152 Bq/kg for Ra-226 and from less than the detection limit up to 1350 and 3001 Bq/kg for Th-232 and K-40, respectively. The average Ra-226, Th-232 and K-40 concentrations in the industrial by-products were, respectively, 2.52, 2.35 and 0.39 times those in the raw materials — this illustrates why, when considering possible radiation exposure, the radionuclide content of such by-products generally cannot be ignored.

In this study, the absorbed gamma dose rate received by an individual was calculated using a model room with a 20 cm wall thickness and with various densities of material, using activity concentration data for Ra-226, Th-232 and K-40 obtained from the database. The dose calculation was carried out using (i) a fixed density of 2350 kg/m³ in accordance with the modelling method adopted in Ref. [4] and (ii) the actual densities obtained from the database in accordance with the modelling method adopted in Ref. [7]. The I-indices of the building materials were also calculated and compared with the absorbed gamma doses determined using the two different calculation methods. The absorbed gamma doses were compared and clearly showed that without density consideration the calculated dose is significantly higher in the case of low density building materials (see Fig. 2(a)). For densities less than 1000 kg/m³, the overestimation can be as high as 60–70%. This is the reason why, with density consideration, the calculated I-indices correspond to a lower dose rate, which clearly proves the overestimation of I-index in connection with generated dose rate (see Fig 2(b)).

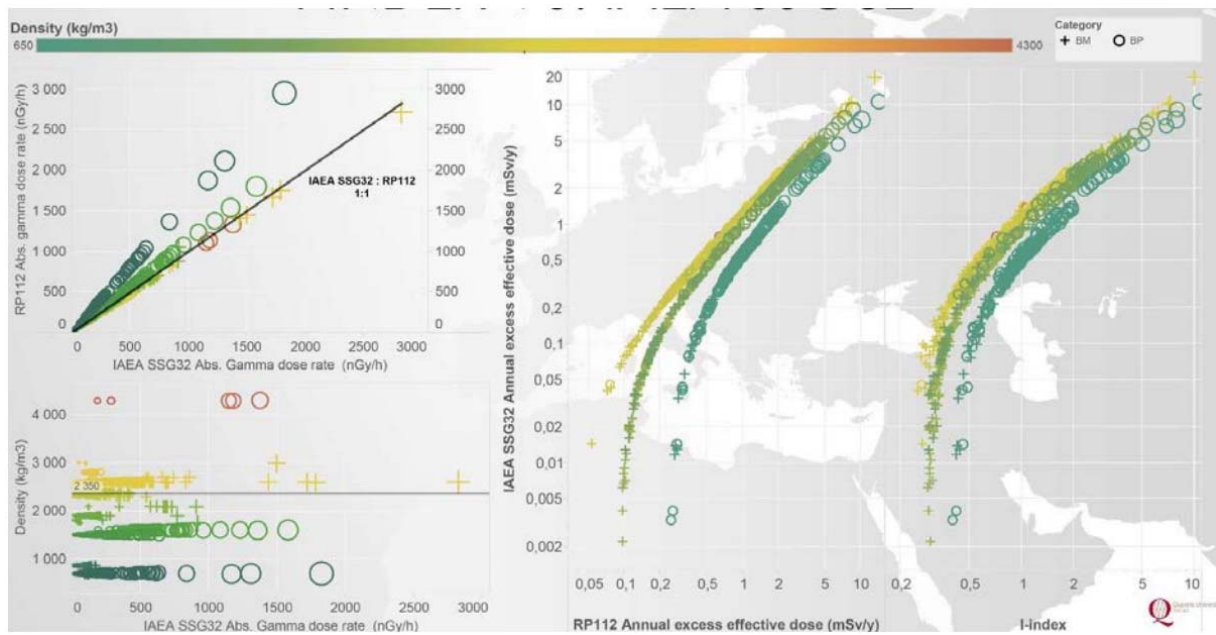


FIG. 2a.: Overestimation without density consideration of absorbed dose

FIG. 2b.: Annual dose excess calculated with different methods in the function of I-index

Conclusion

It was found that in most cases the application of the I-index approach without density consideration provides a significant overestimation of the dose arising from building materials. It means that the I-index provides a conservative and superficial approximation. In the case of building materials with low density, such as commonly used cellular lightweight concrete bricks, this can result in a significant overestimation of dose and an unnecessary restriction on their use.

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